DETERMINATION OF LANE CHANGE MANEUVERS USING NATURALISTIC DRIVING DATA

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ABSTRACT

Heavy truck on board yaw rate recordings are used to discriminate between different driving maneuvers and motions such as turning a curve, changing lanes, or wandering in a road lane. Such discrimination is important for trucks using a front end radar as a sensor for adaptive cruise control and collision warning systems. Turns can cause radar returns from objects outside the roadway or confuse the adaptive cruise control operation. A methodology for determination of a maneuver is derived and then applied to driving data. Correlation of the results is validated by the use of video data. The method has been found to be approximately 80% accurate in identification of the truck maneuver.

INTRODUCTION

The Yaw Rate signal was recorded in the use of a fleet of commercial truck vehicles for a period of two years in a field operational test (FOT). The original intent of recording yaw rate was to determine truck lane change maneuvers. It was hypothesized that a lane change maneuver would generate a Yaw Rate signal that approximates a noisy sine wave as the vehicle moves from the current lane to an adjacent lane. The amplitude and frequency of the yaw rate signal determines the exact nature of the maneuver in that it could be a vehicle turn, multiple lane change, a single lane change, or just small variations within the same lane. In this regard the yaw rate signal for a lane changes and curves differs from that of a signal where the vehicle is wandering within the same lane. It was found that the sinusoidal pattern was indeed reflected in the recorded FOT data mixed in with noise and signal variations due to roadway changes, truck vibration, and driver differences. These factors were all dealt with to define an algorithm that reliably determined the occurrence of a lane change. Development of the algorithm was validated using video data to ascertain the maneuver for a given yaw rate pattern.

BACKGROUND

For short time periods of a few seconds, a simplified model of a vehicle trajectory may be used to determine lateral movement vs. steering input.

The recorded yaw rate $\dot{\gamma}$ may be described by the equation:

$$\dot{\gamma} = K \cdot \sin \alpha$$

Where K is a constant and α is the vehicle steering angle. The yaw angle at any time point, i, may be determined by the following equation,

$$\gamma_i(t) = \sum_{i=1}^{n} \dot{\gamma}_i \Delta t$$

Where Δt is the time increment between any two successive time points. The respective components of the horizontal (x) and longitudinal (y) velocity are expressed as follows.

$$Vx = V \sin \gamma$$

$$Vy = V \cos \gamma$$

This allows the computation of the horizontal and longitudinal displacement equations.

$$Dx(i) = Vx(i)\Delta t + Dx(i-1)$$

$$Dy(i) = Vy(i)\Delta t + Dy(i-1)$$

From the above equations $Dx(i)$ is the current horizontal position of the vehicle at any arbitrary time.

METHODOLOGY

In general, a single sinusoidal signal is sought out of the entire Yaw Rate trace and one cycle of this signal must be of sufficient amplitude, polarity, and duration to represent a lane change as described in the following paragraphs. An algorithm was developed to compute horizontal position from the recorded data. This computation required several steps to remove noise and determine the nature of the signal as follows.

Bias Removal

It turned out that the raw recorded Yaw Rate signal had a bias added to it such that the expected sinusoidal function is not centered around zero for one cycle for a lane change. The bias was therefore removed as part of the post-processing procedure by computing the median value of Yaw Rate followed by subtraction of the median value from every Yaw Rate time point, which in net effect produces a Yaw Rate signal with zero median value. The source of the removed bias is not well known; but ideally should not exist at all. Therefore, it is removed.

Threshold of the Yaw Rate Signal

Due to ambient noise, the algorithm requires that the value of Yaw Rate at each time point exceed the threshold of 0.05 degrees per second. If the threshold is exceeded, the value is retained otherwise the signal is given the value of zero. This is done for all time points from beginning to end of the trace.

Sine Wave First Half Cycle Determination

It was necessary to determine if the yaw rate signal approximated a sine wave. This was done by estimating the period of the sine wave. The potential sine wave pattern was examined to see if a first half cycle occurred within the Yaw Rate signal trace. To do this, both the period and the amplitude of candidate sine waves are examined. If a half cycle sine wave is found, then following that, the total cycle of the sine wave must be found. If a half cycle sine wave is not found, then it is determined that no lane change occurred; but some other maneuver is still possible. Figure 1 shows an idealized example of signals and computations of horizontal position. Figure 2 shows an example of the difference in horizontal displacement for a lane change at different speeds with a yaw rate period of 2 seconds.

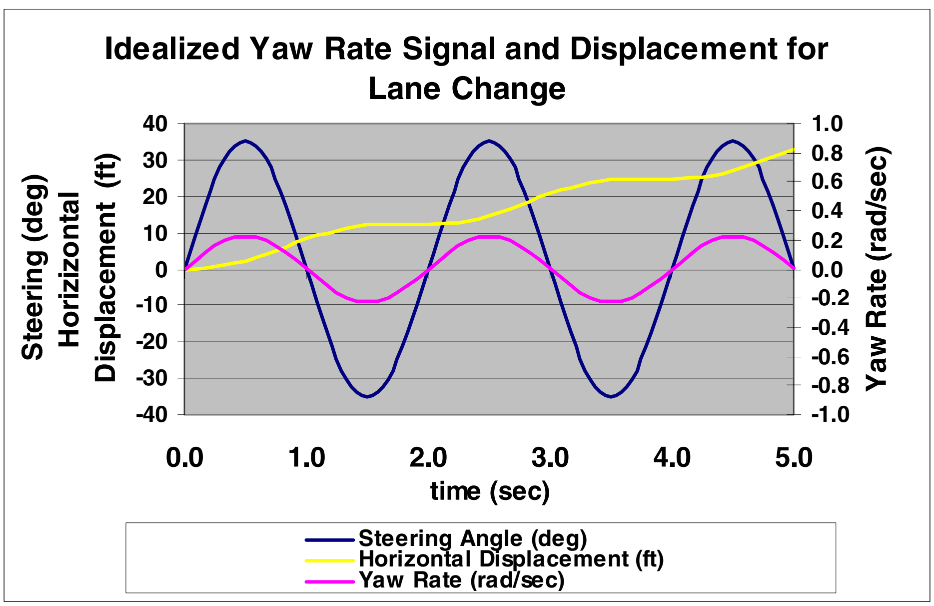

Figure 1. Example of Displacement Due to Lane Change

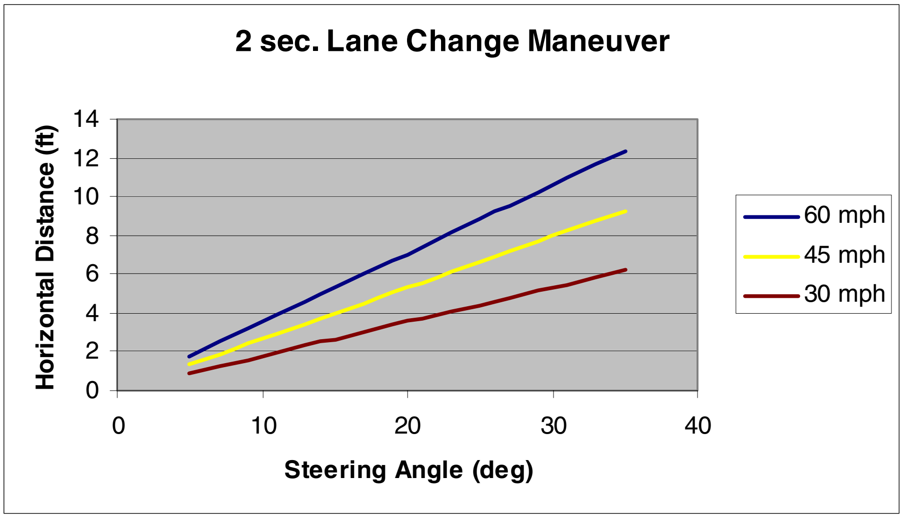

Figure 2. Effect of Vehicle Speed on Horizontal Distance

To ascertain the existence of a first half cycle sine wave, all of the zero crossings of the Yaw Rate signal are isolated. Next, a time threshold is used to see if two successive zero crossings have a period of greater than 1.83 seconds. This period was determined based on the time required for the truck to make a lane change and for that lane change to be reflected in the yaw rate signal. Any two zero crossings with a lesser time span are not considered as being a valid part of a sinusoid that could be used to determine lane change. Such a signal could be the result of merely wandering within the same lane. Any zero crossings equal to or greater than the threshold represent a valid half cycle sine wave. Thus, half of the sine wave is potentially determined. Recognition of a total sine wave, however, is required to detect a lane change.

Total Time Span of Sine Wave

If a valid first half cycle sine wave is found , then the total time span for the sine wave must be determined. In order for a lane change to be recognized, three successive zero crossings for the sine wave are determined as was previously done. All three zero crossings must all be within a time period of 12 seconds; otherwise a maneuver such as turning a curve would be implied.

Thus, the third successive zero crossing determines the end point of the sinusoid. To find this point, small amplitude variations around the second zero crossing are ignored until a zero crossing close to the period of the first half cycle is found. The amplitudes of both half cycles should be close to the same magnitude. In finding this third zero crossing, the period of the sine wave is now known. If this test is failed, then it is determined that no lane change occurred.

Sine Wave Amplitudes

This check is made to see if the amplitudes of the two half cycles are of opposite sign. The first half cycle must be followed by a half cycle of the opposite sign in amplitude. When the Yaw Rate first half cycle is positive, the lane change is from the left lane to the right lane; and if the first half cycle of the signal is negative, the lane change is from the right lane to a left lane. If the amplitudes of both half cycles are not of the opposite sign, then the Yaw Rate does not represent a lane change.

Wandering In Lane

A final check is made to see if the amplitudes are less than 0.5 degrees per second which represents normal “Wandering in the Lane” (WIL) rather than a lane change.

Thus, the algorithm must test to find a sinusoid that meets the other criteria. If a sinusoid fails any one of those tests, it is then subjected to a WIL test; and failing that is deemed not to be a lane change. The four decisions that can result from the algorithm are no lane change, lane change from right to left, lane change for left to right, or wandering in the lane.

SUMMARY

It can be seen that horizontal displacement that results from steering action is reflected in both the amplitude and the frequency of the yaw rate signal. If the yaw rate amplitude is below the noise threshold, horizontal displacement cannot be computed. Yaw rate amplitude much less than that produced by a steering angle of 30 degrees but at the same frequency as a true lane change results in some wandering within the same lane. Yaw rate frequency much lower than that required for a lane change but at a similar amplitude as a lane change amounts to negotiation of a curve. In a curve maneuver, the driver is keeping the steering wheel in some angular position for a longer period without returning it to home resulting in a very low frequency sinusoid. The resultant horizontal displacement of these three effects may be observed in Figures 1 and 3 thru 5.

PERFORMANCE RESULTS

A limited number of video clips were available for verification of the algorithm results. From 105 usable videos, the lane change algorithm had a detection reliability of 80 per cent as shown in Figure 6 below. This reliability rate was deemed reasonable and used for further analysis of driving data from the FOT.

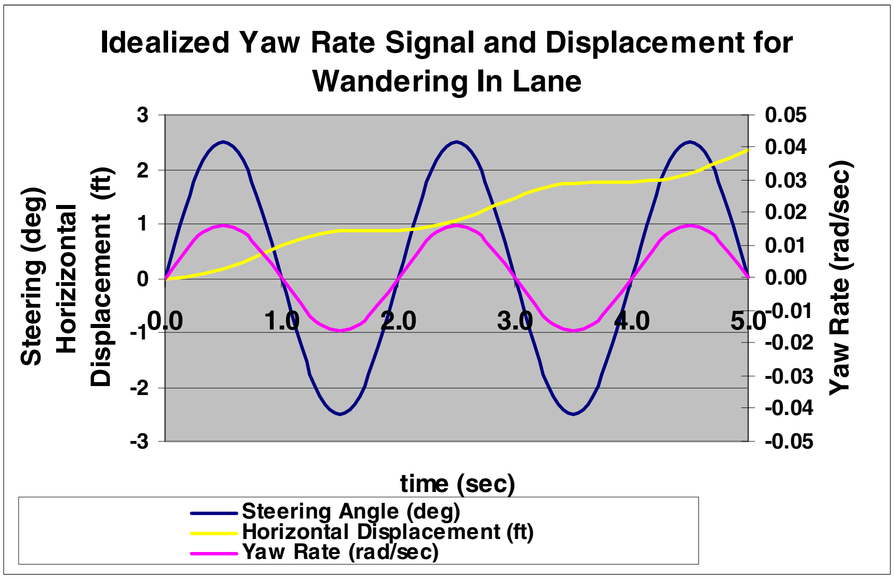

Figure 3. Wandering In Lane Functions

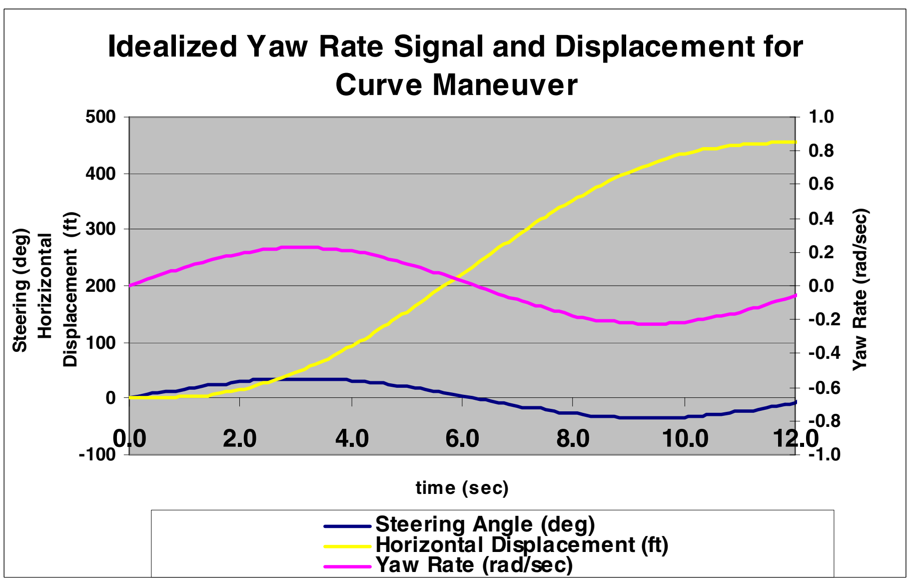

Figure 4. Curve Functions

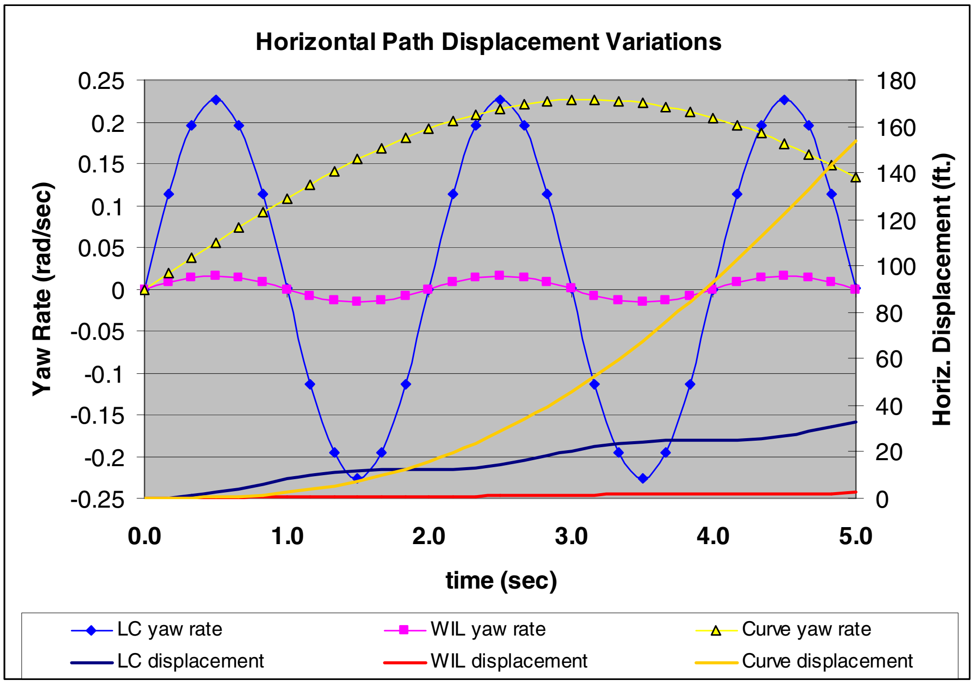

Figure 5. Summary Displacements vs. Yaw Rate Signals

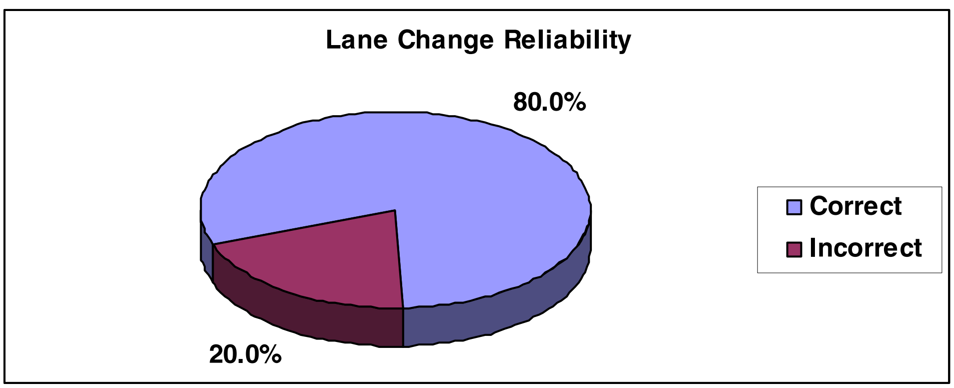

Figure 6. Lane Change Algorithm Performance